RAINFALL RUNOFF SIMULATION USING SLOP ADJUSTED CURVE NUMBER IN KUANTAN RIVER BASIN

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A project report submitted in partial fulfillment

Of requirements for the award of degree of

Bachelor of Science (Hons) Civil Engineering and Earth Resources

Faculty of Civil Engineering & Earth Resources

UNIVERSITI MALAYSIA PAHANG

JULY 2015

ABSTRACT

The Natural Resources Conservation Service Curve Number (NRCS-CN) method is widely used for predicting direct runoff from rainfall. It believed that NRCS-CN has developed in an agricultural land with slope less than 5%, therefore it do not consider the effect of slope in the hilly and mountainous watersheds. Some researchers have investigated the effect of terrain slope on CN estimation. But on research can be found for assessment of slope on modified CN value and it is always a problem to find suitable source of elevation data to create slope map. It is significant that this is the first report on adjustment of Cell-based CN to determine the slope adjustment for CN using Sharply-Williams integrated with ASTER-GDEM. The adjusted CN was then tested for 25 observation rainfall runoff data. New slope adjusted CN demonstrate significant improvement from 0.12 to 0.39 in runoff estimation. This methodology can be carried out in different climate condition to get more inside CN for runoff estimation.

ABSTRAK

Sumber Asli Pemuliharaan Perkhidmatan Curve Number (NRCS-CN) kaedah yang digunakan secara meluas untuk meramalkan air larian terus dari hujan. Ia percaya bahawa NRCS-CN telah dibangunkan di tanah pertanian dengan cerun kurang daripada 5%, oleh itu ia tidak menganggap kesan cerun di kawasan tadahan air bukit dan pergunungan. Sesetengah penyelidik telah menjalankan kajian kesan kawasan cerun di CN anggaran. Tetapi penyelidikan boleh didapati untuk penilaian cerun pada nilai CN diubahsuai dan ia sentiasa masalah untuk mencari sumber sesuai data ketinggian untuk mewujudkan peta cerun. Adalah penting bahawa ini adalah laporan pertama mengenai pelarasan berdasarkan Cell-CN untuk menentukan pelarasan cerun untuk CN menggunakan Sharpley-Williams disepadukan dengan ASTER-GDEM. CN diselaraskan kemudiannya diuji untuk 25 pemerhatian data air larian hujan. Cerun baru diselaraskan CN menunjukkan peningkatan yang ketara 0,12-0,39 dalam anggaran air larian. Metodologi ini boleh dilakukan dalam keadaan iklim yang berbeza untuk mendapatkan lebih banyak di dalam CN untuk anggaran air larian.

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LIST OF ABBREVIATIONS

AMC	Antecedent Moisture Condition
ASTER	Advanced Space-borne Thermal Emission and Reflection
CN	Curve Number
DID	Department of Irrigation and Drainage
GDEM	Global Digital Elevation Models
GIS	Geographical Information System
HEC-HMS	Hydrological Modeling System
HSG	Hydrologic Soil Group
ILWIS	Integrated Land and Water Information System
KRB	Kuantan River Basin
LU	Land Use
NAHRIM	National Hydraulic Research Institute of Malaysia
NASA	National Aeronautics and Space Administration
NRCS-CN	Natural Resources Conservation Service Curve Number
SACN	Slope Adjusted Curve Number
SCS	Soil Conservation Service
SCS-CN	Soil Conservation Service Curve Number
TR55	Technical Release 55

CHAPTER 1

INTRODUCTION

1.1. Background

The rainfall runoff is a complex and non-linear hydrological process with high variability in time and space. Accurate estimation of runoff is critical in urban hydrology, because that is the design base for water resources infrastructures and flood peak discharge. Several methods is used to estimate flood runoff including statistical analysis, empirical equations, frequency analysis, unit hydrograph and so on. Soil Conservation Service Curve Number (SCS-CN) methods is empirical equation which have been widely used in different studies.

The SCS-CN method which is now called Natural Resources Conservation Service Curve Number (NRCS-CN) since 2001, has presented in 1954 by the USDA (Rallison 1980); and revisions has made in 1956, 1964, 1965, 1971, 1972, 1985, 1993 (Ponce and Hawkins 1996).The CN is an empirical parameter used for predicting direct runoff or infiltration from rainfall excess (USDA, 1986, Mahdavi, 2005, Alizadeh, 2006). Regardless of some weaknesses, the CN method presents some advantages such as quantification of the effect of landuse changes on runoff formation (Rietz and Hawkins 2000). The widespread popularity of the NRCS-CN method attributes to the wide availability of the required data and its simplicity.

As result, the NRCS-CN method which originally intended for the study of agricultural land, became a fundamental part of hydrological practice and was adopted for application in different climate and conditions (Miliani et al., 2010). Moreover the CN method has been integrated into several hydrologic models, including CREAMS (Knisel, 1980), FEST (Montaldo et al., 2007, Rabuffetti et al., 2008), EPIC (Sharpley and Williams, 1990), AGNPS (Young et al., 1989), HEC-HMS (Feldman, 2000) and SWAT (Neitsch et al., 2005).

There are many research articles and classical books in supporting and criticizing the CN method. Among them the works of Hawkins (1978, 1993), Hawkins et al. (2009), Huang et al. (2006, 2007), Garen and Moore (2005), Mishra et al. (2003, 2006) and Michel et al. (2005) are more remarkable. Review of literature shows that considerable attempted has been made for adjustment and adaptation of CN method for unaccented factors including drainage area (Simanton and Sutter, 1973, Simanton et al., 1996), soil moisture proxies (Ponce and Hawkins, 1996, Garen and Moore, 2005, Beck et al., 2009), slope (Sharpley and Williams, 1990, Huang et al., 2006) and more recently Kakuturu et al. (2013) investigated the effect of slope on estimation of CN values.

In general CN can be considered as indicator which classifies the land parcels in terms of runoff generation capacity based on their usage and storage capacity. In highly flood affected watershed, it is very useful to identify the spatial variation of runoff potential in order to implement flood mitigation projects effectively. The main objective of this research is to develop a methodology for derivation of flood runoff susceptibility map based on the modified SCS-CN.

1.2. Problem Statement

Nowadays there are many area had been fully developed with huge buildings, factory and shopping mall. Rainfall will infiltrate the more in an undeveloped area (pervious) compared to developed area (impervious). As a result, if a very large amount of rainfall in a developed area, only a little of the amount will infiltrate into the soil and the rest of them will flow to the lower level of the ground as runoff. When the quantity of the runoff is increasing and filled all the drainage and river, flood will then occur. To prevent the occurring of the flash flood, we need to determine the rainfall-runoff relationship. Flash flood had occurred in Kuantan Pahang due to drainage capacity cannot cattle the quantity of water when the capacity of runoff increases. This natural phenomenon may bring disaster that may take away human lives and loss of their properties.

In order to prevent this disaster happen, research should be carrying out to analyze the relationship between rainfall and runoff. There are many data that have to be obtaining to determine the rainfall-runoff relationship. In this science and technology era, much software had been created to simplify and also to obtain more accurate result. One of the computer programs that can be used to simplify the data is Geographical Information System (GIS). It is designed to be applicable in a wide range of geographic areas for solving the widest possible range of problems. This includes large river basin water supply and flood hydrology, and small urban or natural watershed runoff. Relationship between rainfall and runoff will then be determined by the producing hydrograph from this software.

1.3. Objectives

In order to make this study successful, three objectives have been determined. It works as a guide line so that the outcomes of this study can be easily achieved.

The following are the objectives of this research:

1. To improve curve number by slope adjustment.
2. To examine the performance of slope adjusted $CN_{0.05}$ in direct runoff estimation
3. To establish a relationship between traditional CN provided in TR-55 (hereafter $CN_{0.2}$) and modified $CN_{0.05}$ to facilitate conversion of $CN_{0.2}$ values to $CN_{0.05}$.

1.4. Scopes of Study

In this study, the Kuantan River Basin hereafter KRB (3.78°N, 103.22°E) is treated. It is the state capital of Pahang the most urbanized area situated near the mouth of the Kuantan River and faces the South China Sea. The climate is more influences by seasonal variation of the northeast monsoon. The main city in this watershed is Kuantan with population of 607,778 in 2012 (Noor and Rosni, 2013) . It is the 9th largest city in Malaysia. Mean annual rain fall of the study area is about 3200 mm.

The study area is located in eastern part of Peninsular Malaysia where the city of Kuantan is Located. Kuantan watershed was selected due to the high growth rate of its population and the rapid establishment of new town area (Noor and Rosni, 2013). It is identified as one of the future growth centers and a hub for trade, commerce; transportation and tourism. The watershed area is about 167437 ha, Elevation range from 0 at the mouth of watershed to 1511m in the most remote part of north-west of watershed.

Serval major flood events have been reported in KRB specifically flood events occurred in December 2013, December 2014 and January 2015. There may be serval reason behind the frequent flood in KRB. Flood susceptibility map may help to provide a closer view to watershed managers, planners, and engineers either from the government bodies or privet sector in flood mitigation activities.

1.5. Significance of Study

From this research, the relationship between rainfall and runoff can be obtained. Besides that, the different of the ArcGIS method that used to analyze the relationship can be determined. It is important to do this research because we can evaluate the performance of the model and its accuracy in predicting runoff in tropical area. It’s also to verify the relationship between the characteristics of rainfall events and runoff with the factors affecting it in the catchment which can cause flood event in Kuantan watershed. The output of this research can bring benefit to the conservation of water resources and flood planning and mitigation, as well as the soil engineering planning and hydrological structure design.

CHAPTER 2

LITERATURE REVIEW

2.1 Hydrology

Hydrology is a branch of physical geography which deals with the origin, distribution, and properties of water through the air, over the ground surface and through the earth strata. The knowledge of hydrology is of basic importance in all walks of life that involve the use and supply of water and any propose what so ever. Therefore, the knowledge of hydrology is not only useful in the field of engineering, but also in agriculture, forestry and other branches of natural science (Gupta, 1979).

2.1.1 Importance of Hydrology

In engineering hydrology is used mainly in connection with the design and operation of hydraulic structures. Therefore, with the advancement in flood control, irrigation, and power generation and etc. the importance of hydraulic structure is gaining importance (Wikipedia, 2005).

2.2 Hydrologic Cycle

The hydrologic cycle is defined as the pathway of water as it moves in its various phases through the atmosphere, to the earth, over and through the land, to the ocean, and back to the atmosphere (National Research Council, 1999). The movement of water in the hydrologic cycle is illustrated in Figure 2.0.

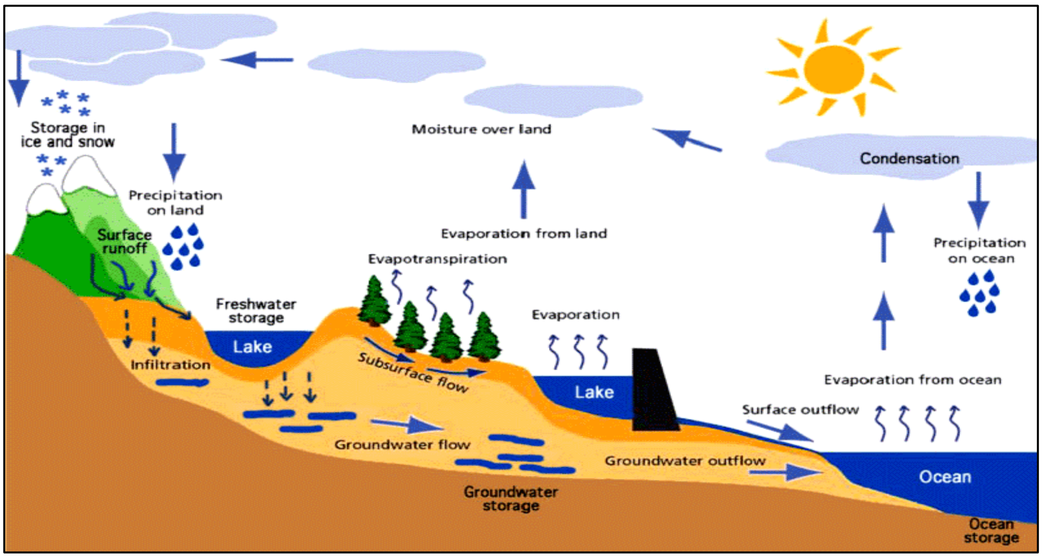

Figure 2.0: Main Component of Hydrologic Cycle

A description of the hydrologic cycle can start with the evaporation of water from the ocean driven by energy from the sun. The evaporated water, in the form of water vapor, rise by convection; condenses in the atmosphere to form clouds; and precipitates onto land and ocean surfaces as rain or snow. Precipitation on land surfaces is partially intercepted by surface vegetation, partially stored in surface depressions, partially infiltrated into the ground, and partially flows over land into drainage channels and rivers that ultimately lead back to the ocean. Precipitation that is intercepted by surface vegetation is eventually evaporated into the atmosphere; water held in depression storage either evaporates or infiltrates in to the ground; and water that infiltrated into the ground contributes to the recharge of ground water, which is either utilized by plants or becomes subsurface flow that ultimately emerges as recharge to streams or directly to the ocean (Chin, 2000).

2.2 Runoff

Precipitation is the primary source of all waters. When rain starts falling on a more or less previous area it is consumed in many ways such as: the rainfall is intercepted by buildings, trees, grasses, and other objects, preventing it from reaching the ground, some part of it infiltrates into the ground, some part of it finds its way to innumerable small and large depression, if rain continues, the soil surface becomes covered with a film of water and is known as surface detention and flow begins to start to words an established surface channel. Thus, runoff may be defined as that part of precipitation as well as of any other flow contribution which appear in surface streams (Gupta, 1979).

2.2.1 Sources of Runoff

The water flowing in a stream may have reached there from many sources such as: precipitation falling directly on the surface of the stream and its distributes, surface runoff is the portion of the precipitation which after falling on the ground surface finds its way into the stream channels without infiltrating into the soil and percolating down to the water table. Sub-surface flow is the part of precipitation which first infiltrates into the soil, moves laterally and joints the river channel before joining the water table below. Usually it is treated as surface runoff as it takes very little time to reach the river channel in comparison ground water and ground water is the portion of precipitation which after falling on the ground surface infiltrates into the soil and joined the ground water, and then after sometime found its way through the soil into the stream (Gupta, 1979).

2.2.2 Factors Affecting Runoff

The factors affecting runoff from any catchment area may be group into the following two groups; precipitation characteristics and physical characteristic of the basin.

2.2.3 Precipitation Characteristics

Precipitation characteristics include; types of precipitation, intensity of rainfall, duration of rainfall, distribution of rainfall, direction of storm movement, soil moisture and other climate conditions.

2.2.3.1. Types of Precipitation

The type of precipitation has a great influence on runoff. For instance of precipitation take place in the form of rainfall, its water will start flowing on the surface with in no time after the start of rain fall depending upon its intensity and magnitude.

2.2.3.2. Intensity of Precipitation

The intensity of rainfall affects runoff to get a great extent. The rain fall exceeding the infiltration capacity of the soil generates surface runoff very rapidly with the increase in rain fall intensity. Rain fall with higher intensity will generate more runoff than low intensity rain fall, through total amount of rain fall may be equal.

2.2.3.3. Duration of Rainfall

The duration of rain fall affects the runoff due to the fact that during a rain fall the infiltration capacity of the soil goes on reducing till it attains a constant value. As a result of this fact, even a mild intensity of rain fall may produce considerable surface runoff. Further if rains continue over an extended period, the water table may rise and sometimes even may touch the ground surface in low lying areas, reducing the infiltration capacity to zero of that area and there may be chances of serious flood hazard.

2.2.3.4. Distribution of Rainfall

For small drainage basins high peak flows are generally the result of intense rains falling only on small areas. On the other hand for large drainage basins the high peak flows are usually produced by storm of less intensity, but covering very large area. Thus, the runoff from a drainage basin depends very much on the distribution of rainfall. The rainfall distribution can be expressed by the distribution coefficient. For a given storm the distribution coefficient can be obtained by dividing the maximum rain fall at any point by the mean rainfall of the basin. For a given total rainfall all other conditions being the same, greater the coefficient of distribution, greater will be the peak runoff. However, for the same distribution coefficient, the higher peak runoff would result for the storm falling on the lower part of the basin.

2.2.3.5. Direction of Storm Movement

The direction in which the storm travels across the basin with respect to the direction of flow of the drainage system has a great influence upon the resulting peak flow and also the duration of surface runoff. It has been observed that the storm moving in the direction of the movement of water in the drainage basin, will produce more runoff and the water will remain u-in the basin for shorter duration as compared to the case when storm moves in the opposite direction of the water of the basin.

2.2.3.6. Soil Moisture

The amount of moisture in the surface layers of the soil at the time of rainfall has a marked effect on the surface runoff, as the soil moisture affects infiltration capacity very much. If the rainfall takes place after a long dry spell of time when the soil is dry and can absorb a large amount of water, in such conditions even intense rainfall may fail to produce any appreciable runoff. On the other hand, if the rainfall takes place when the soil moisture content is high i.e. after a long rainy season, in such situation the infiltration will be very leak and even very small rainfall may produce peak flows and cause considerable rise in stream water level, sometimes disastrous flood also.

2.2.3.7. Other Climate Conditions

Climate factors such as temperature, wind velocity, relative humidity, annual rainfall, etc will affect the losses from the drainage basin to a great extent and thus affect the runoff. If the losses are more, the runoff will be less and vice versa.

2.2.4 Physical Characteristic of the Basin

Physical characteristic of the basin include: land use, elevation of the basin and slope of the drainage.

2.2.4.1. Land Use

The land use or land management has a great effect on the resulting surface runoff. Consider a virgin forest area, in which a thick mulch of leaves and grass etc has accumulated. In such areas even the heaviest down pours or rains would be unable to generate surface runoff that would reach the streams. On the other hand if the forest is removed and the land is cultivated after removing the mulch, the ground will become compacted. As a result of which even a mild rainfall will result in appreciable surface runoff.

2.2.4.2. Elevation of the Basin

The elevation of the basin also effects the runoff as it governs the rainfall, its type and amount. Higher the elevation, lesser the losses. At higher elevations much of the precipitation is impounded in the form of snow etc.

2.2.4.3. Slope

The slope of the drainage has an important, but complex effect of the runoff. It control the time of over land flow and concentration of rain fall in stream channels. In case of steeper basins the velocity of flow will be more and runoff will take lesser time to reach the stream, resulting in higher runoff.

2.3 Rainfall Runoff Relationship

During a given rainfall, water is continually being abstracted to moisten the upper levels of the soil surface; however, this infiltration is only one of many continuous abstractions. Rainfall is also intercepted by trees, plants, and roof surfaces, and at the same time is evaporated. Once rain fall and fulfills initial requirements of infiltration, natural depressions collect falling rain to form small puddles, creating depression storage. In addition, numerous pools of water forming detention storage build up on permeable and impermeable surface within the watershed. This stored water gathers in small rivulets, which carry the water originating ass overland flow into small channels, then into larger channels, and finally as channel flow to the watershed outlet (Lewis and Viessman, 2003).

The infiltration capacity of the soil depends on its texture and structure, as well as on the antecedent soil moisture content (previous rainfall or dry season). The initial capacity of a dry soil is high but, as the storm continues, the soil capacity will decrease until it reaches a steady value as final infiltration rate (Lewis and Viessman, 2003). The rainfall-runoff relationship is shown in Figure 2.1.

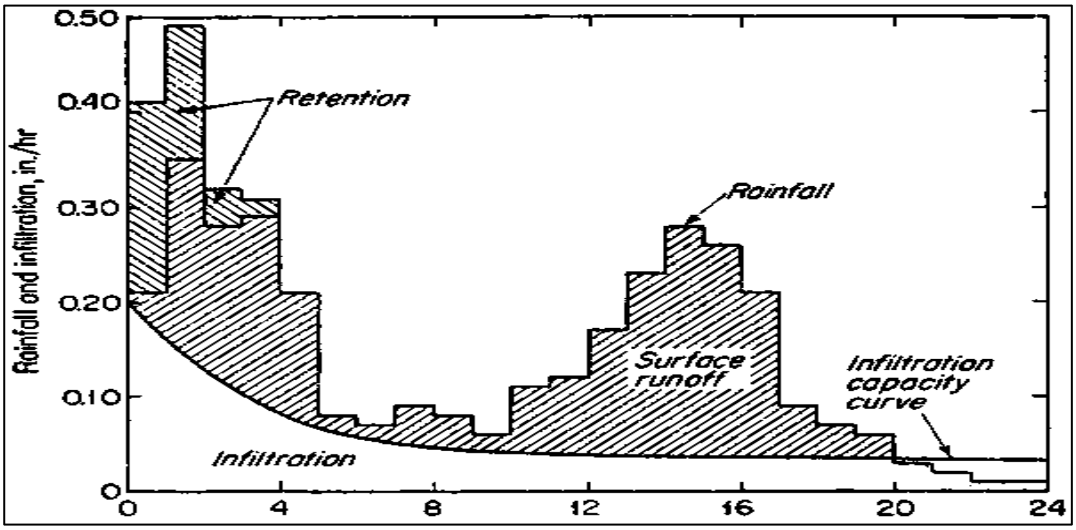

Figure 2.1: Schematic diagram of rainfall runoff relationship

The process of runoff generation continues as long as the rainfall intensity exceeds the actual infiltration capacity of the soil but it stops as soon as the rate of rainfall drops below the actual rate of infiltration.

2.3.1 Hydrograph

The flow in a stream in a certain period of time can be representing by a unit hydrograph. A hydrograph has four component elements; direct runoff, interflow, base flow and channel precipitation. The rising portion of the